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Overview of environmental impacts, prospects and policies for renewable energy in Taiwan

W.T. Tsai [a,*], Y.H. Chou [b]

[a] *Department of Environmental Engineering and Science, Chia Nan University of Pharmacy and Science, Tainan 717, Taiwan*

[b] *Department of Applied Foreign Languages, Chia Nan University of Pharmacy and Science, Tainan 717, Taiwan*

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Abstract

Taiwan is a high energy-dependent nation with about 97% of our energy needs supplied by imported fuels in 2002. Environmental pollution and greenhouse gas emissions are becoming significant environmental issues in the country. In this regard, renewable energy is thus becoming attractive in recent years based on the energy policy for the sustainable development and environmental pollution mitigation in Taiwan. In response to the balance between economic development, energy supply stability and environment protection, the Energy Commission under the Ministry of Economic Affairs has issued the Renewable Energy Development Plan in 2001. The objective of this paper is to present an updated overview of current utilization and future development on renewable energy, including biomass energy, solar energy (i.e., photovoltaic power and solar water heating), wind energy and geothermal energy. The description is first centered on energy production/consumption situation and greenhouse gas emissions status, and then concerned with renewable energy utilization in terms of environmental impacts, especially in air pollution. Finally, we present the promotion measures related to the renewable energy utilization under the government regulations, industrial policy, financial incentives and funding supports.

Keywords: Renewable energy; Promotion measure; Energy policy

* Corresponding author. Tel.: +886-6-2660-393; fax: +886-6-2669-090.
E-mail address: wwtsai@mail.chna.edu.tw (W.T. Tsai).

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Contents

1. Environmental background

Taiwan is a subtropical nation, located in the southeastern rim of Asia and faces the Pacific Ocean in the east and the Taiwan Strait in the west. The small country comprises the island of Taiwan and the Penghu archipelago with a total area of ca. 36,000 km^2, that is 377 km long (i.e., 119° E–124° E in longitude) and 142 km wide (i.e., 21° N–25° N in latitude). Geographically, Taiwan can be divided into four regions—northern region (including Taipei city, Taipei county, Keeling city, Taoyuan county, Hsinchu county, Hsinchu city), central region (including Miaoli county, Taichung county, Taichung city, Changhua county, Nantou county, Yunlin county), southern region (including Penghu county, Chiayi county, Chiayi city, Tainan county, Tainan city, Kaohsiung county, Kaohsiung city, Pingtung county), and eastern region (including Yilan county, Hualien county, Taitung county). By the end of 2002, Taiwan with a population of over 22 millions ranked second in population density in the world. Evidently, Taiwan is a densely populated island with heavy environmental indicators, as seen in Table 1 [1].

Table 1
Environmental indicators during 1987–2002 in Taiwan[a]

Year	Population		Mobile vehicle[b]		Factory[c]		Pig in raising	
	Person	Density (person/km^2)	No.	Density (No./km^2)	No.	Density (No./km^2)	No.	Density (head/km^2)
1987	1967×10^4	546	754×10^4	209	84,163	2.34	713×10^4	198
1988	1990×10^4	553	843×10^4	234	90,607	2.52	695×10^4	193
1989	2011×10^4	559	928×10^4	258	93,925	2.61	778×10^4	216
1990	2035×10^4	565	1005×10^4	279	92,978	2.58	857×10^4	238
1991	2056×10^4	571	1061×10^4	295	95,327	2.65	1009×10^4	280
1992	2075×10^4	576	1127×10^4	313	94,673	2.63	975×10^4	271
1993	2094×10^4	582	1186×10^4	329	96,631	2.68	984×10^4	273
1994	2113×10^4	587	1238×10^4	344	95,582	2.66	1007×10^4	280
1995	2130×10^4	592	1320×10^4	367	97,013	2.69	1051×10^4	292
1996	2147×10^4	596	1427×10^4	396	96,820	2.69	1070×10^4	297
1997	2168×10^4	602	1531×10^4	425	99,845	2.77	797×10^4	221
1998	2187×10^4	607	1592×10^4	442	98,836	2.74	654×10^4	182
1999	2203×10^4	612	1628×10^4	452	100,682	2.80	724×10^4	201
2000	2222×10^4	617	1698×10^4	472	98,833	2.74	749×10^4	208
2001	2234×10^4	620	1742×10^4	484	97,182	2.70	716×10^4	199
2002	2245×10^4	624	1786×10^4	496	98,195	2.73	679×10^4	189

[a] Ref. [1].
[b] Including motorcycles and cars that registered in the Responsible Agency in the central government.
[c] Factories that registered in the Responsible Agency in the central government (i.e., MOEA).

With the rapid industrialization in the past three decades, Taiwan is now on the way to developed countries. In the 1970s, heavy industries developed at great speed. But the speed of this development and Taiwan's land shortage and high population density also impose heavy strain on the environmental and energy loadings. From the mid-1980s, the industrial sector's share of the economy began to decline while the service sector showed an upward trend. Meanwhile, the government promoted strategic industries that are characteristics of low energy consumption, high added value, high-tech, low pollution, and great export potential as a useful mean to adjust the structure of Taiwan's sector. With respect to economic development since 1970s, the nation's rapid industrial development has led to continuous economic growth. In 1992, average gross national product (GNP) per person rose above US$ 10,000. In 1995, it was over US$ 12,000. During the 19 years from 1984 to 2002, excluding the years 2001 and 2002 when the economic growth rate fell below 4%, the economic growth rate ranged from 4.57% to 12.74%. Key economic indicators in Taiwan can be seen in Table 2 [2].

With the Taiwan's economic development called "economic miracle", heavy environmental loadings in Taiwan listed in Table 1 caused some serious environmental scenarios such as air quality deterioration, river water pollution,

Table 2
Economic indictors during 1984–2002 in Taiwan[a]

Year	GDP[b] (million US$)	GNP[c] (US$ per capita)	Economic growth rate (%)
1984	59,139	3167	10.60
1985	62,062	3297	4.95
1986	75,434	3993	11.64
1987	101,570	5298	12.74
1988	123,146	6379	7.84
1989	149,141	7626	8.23
1990	160,173	8111	5.39
1991	179,370	8982	7.55
1992	212,200	10,506	7.49
1993	224,266	10,964	7.01
1994	244,278	11,806	7.11
1995	264,928	12,686	6.42
1996	279,611	13,260	6.10
1997	290,201	13,592	6.68
1998	267,154	12,360	4.57
1999	287,881	13,235	5.42
2000	309,426	14,188	5.86
2001	281,178	12,876	−2.18
2002	281,508	12,900	3.54

[a] Ref. [2].
[b] Gross Domestic Product.
[c] Gross National Product.

illegal dumping and non-sanitary landfill of industrial and municipal solid wastes [3]. As a result, the Taiwan Environmental Protection Administrations (EPA), the primary central government-level agency responsible for environmental issues, began to promulgate stringent regulation to establish an integrated management system for environmental protection. Recently, environmental policy in Taiwan, combined with economic upgrading and energy policy, has adopted incentive measures such as tax deduction, research and development (R & D) subsidies and investment subsidies as a means of acquiring environmental benefits to pursue sustainable development [4]. In December 2002, the Fundamental Environment Act was finally promulgated by the Legislative Yuan, serving as a polestar for national environmental policy on sustainable development relating to the balance of environmental, economic, technological and social developments. Further, the act also safeguards Taiwan's environmental quality by referring to the United Nations Framework Convention on Climate Change (UNFCCC) and other global environmental issues.

The imported energy in Taiwan accounts for approximately 97% of the total energy supply in this subtropical country with only limited natural resources. With the rapid industrialization and economic development in the past decades, the national energy consumption tends to be larger with economic growth, resulting in high-energy dependence [5]. In 2000, energy supply totaled 106.23 million kiloliters

of oil equivalent (KLOE), in contrast to 58.57 KLOE in 1990 [1]. In recent years, the global environmental issues such as global warming and sustainable development are consecutively raising public concerns. In response to the Kyoto Protocol adopted in December 1997, Taiwan convened the National Energy Conference in May 1998. One of the most important conclusions was to increase the share of renewable energy in Taiwan's total energy supply, up to 3% in 2020. For this reason, energy strategies and policies for promoting renewable energy must be active in providing some environmental, financial and economic incentives. With respect to energy policy for economic development and sustainable development, the Executive Yuan has revised and approved "The Energy Policy of the Taiwan Area", implemented by the Energy Commission under the Ministry of Economics Affairs [6], primary agency responsible for industrial development and energy policy in the central government level. The relevant points of energy policy include the production of clean energy, mitigation of greenhouse gas emissions and reinforcement of renewable energy research and development.

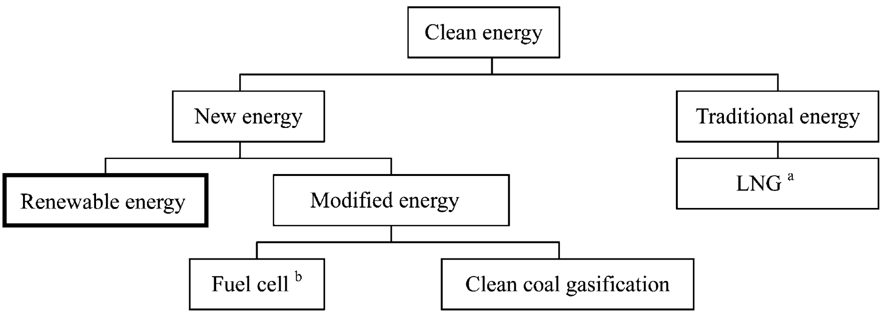
The consumption of conventional fossil fuel (especially coal and petroleum) and adoption of hydropower energy are inevitably accompanied by human activities that polluted and damaged the environment, and also exhausted the natural resources. Nuclear energy also creates pollution problems in treating and storing radioactive wastes. Since the energy crisis in the 1970s, government policy in several developed (e.g., USA, Germany, Japan) and developing countries (especially China, India and Brazil) had been focused upon the so-called clean energy or renewable energy such as wind energy, biomass energy and solar energy (see Fig. 1). The objectives of this paper will present an updated review and innovative information on energy utilization from renewable resources in Taiwan. These approaches and progresses will be expected to offer cost-effective measures for other developing countries. The term renewable energy addressed in the present paper refers the potential and available energy sources, including solar energy, wind energy, biomass energy and geothermal energy. The main subjects covered in this paper are listed in the following key elements:

- Status of energy supply and consumption.
- Status of greenhouse gas emissions.
- Environmental impacts of renewable energy utilization.
- Promotion policies for encouraging renewable energy.
- An overview of current renewable energy usage.

2. Status of energy supply and consumption

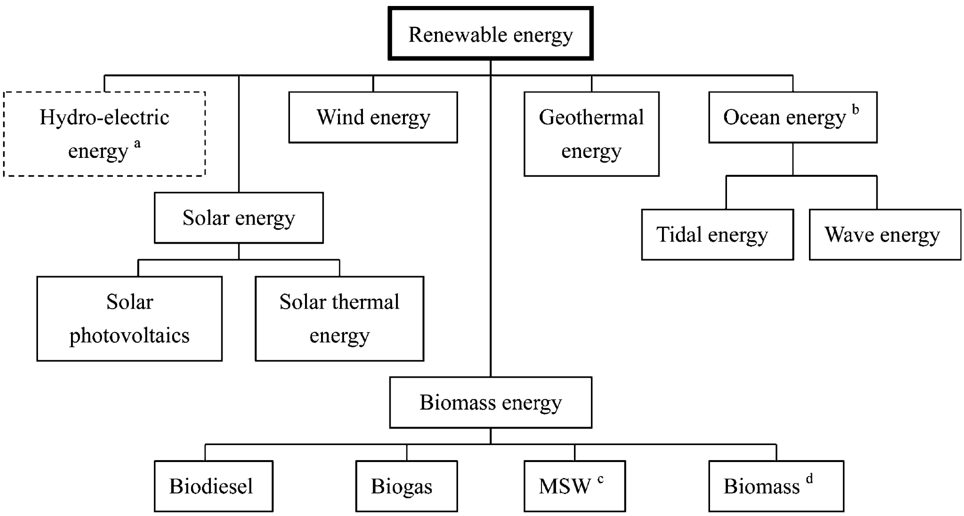
The increasing demand for energy has tailed on economic growth and raised living standards in Taiwan. It, however, is a high energy-importing country. National reliance on imported energy rose from 77.3% in 1977, 86.2% in 1982 to 97.1% in 2000 and 97.8% in 2002 (see Table 3). Due to the efforts to diversify energy sources, the reliance on oil reduced from 76.9% in 1977 and 63.6% in 1982

(a)



a. Liquefied natural gas
b. Fuel cell with hydrogen energy from biomass source belongs to one of renewable energy

(b)



a. Not discussed in the present paper due to the environmental considerations.
b. Not currently available in Taiwan.
c. Municipal solid waste.
d. Such as agricultural wastes/by-products.

Fig. 1. The categories of (a) clean energy, and (b) renewable energy discussed in the paper.

to 51.4% in 2000 and 49.3% in 2002. With respect to the energy supply and consumption during 1982–2002 in Taiwan (see Table 4) [5], the notable points are addressed as follows:

Table 3
Energy indicators during 1982–2002 in Taiwan[a]

Item	1982	1992	2002
Total energy supply[b] (million KLOE)	31.8	64.1	113.2
Domestic energy consumption (million KLOE)	29.0	58.3	100.0
Imported energy ratio (%)	86.20	94.97	97.79
Value of energy imports/value of total imports (%)	25.81	8.03	10.16
Value of energy imports/GDP[c] (%)	9.27	2.73	5.52
Energy imports per capita (NT$)[d]	10,437	7056	17,843
Energy consumption per capita (LOE)[e]	1584	2820	4463
Energy productivity (NT$/LOE)	90.86	101.85	96.31
Energy intensity (LOE/1000 NT$)	11.01	7.82	10.38
Dependence on crude oil imported from the Middle East (%)	85.07	79.98	73.54
Dependence on oil (%)	63.60	53.34	49.26
Electricity consumption per capita (kW h)	2229	4714	8286

[a] Ref. [5].
[b] Kilo Liter per Oil Equivalent.
[c] Gross Domestic Product.
[d] 1 US$ ≒ 34 NT$.
[e] Liter of Oil Equivalent.

- Prior to 1982, the energy supply from indigenous production is above 14%. The portion, which the domestic production accounted for, has gradually diminished since then. In 2002, 98% of energy sources were imported.
- The energy supply increased from 31.8 million KLOE in 1982 to 113.2 million KLOE in 2002. The growth rate of energy supply averaged out at about 6.5%. On the other hand, the domestic energy consumption increased from 29.0 million KLOE in 1982 to 100.0 million KLOE in 2002. The growth rate for domestic energy consumption averaged at about 6.4%.
- In response to the oil crisis, the government has diversified its energy sources. Only 49% of the total energy supply in 2002 came from petroleum, compared to 77% in 1977. The second largest energy source was coal with a 33% share of the energy supply by nuclear power (9%), natural gas/liquefied natural gas (8%), hydroelectric power (1%) and renewable energy (below 1%).
- A considerable portions (about 60% and 15%, respectively) of the energy supply are used in industrial sector and transportation sector due to the strategic development on high-tech industries and the rise in living level during the stage of 1982–2002.

According to the data projected by the Energy Commission under the Ministry of Economics Affairs [5], the energy supply and consumption of Taiwan will increase by an average of about 2% per year during the years from 2002 to 2020 (see Table 5). This gradual increase in energy demand is mainly due to the Taiwan's response to the economic, energy and environmental (3E) policies for sustainable development in the near future. The important features in Table 5 are summarized as follows:

Table 4
Energy supply and demand during 1982–2002 in Taiwan[a]

Item	1982	1992	2002
Total supply (m^3, oil equivalence)	31.8×10^6	64.1×10^6	113.2×10^6
Indigenous	4.4×10^6 (14%)	3.2×10^6 (5%)	2.5×10^6 (2%)
Imported	27.4×10^6 (86%)	60.9×10^6 (95%)	110.7×10^6 (98%)
Total supply composition (m^3, oil equivalence)	31.8×10^6 (100%)	64.1×10^6 (100%)	113.2×10^6 (100%)
Petroleum	20.2×10^6 (64%)	34.2×10^6 (54%)	55.7×10^6(49%)
Coal	5.7×10^6(18%)	16.2×10^6(25%)	37.5×10^6(33%)
Nuclear power	3.3×10^6(10%)	8.4×10^6(13%)	9.8×10^6(9%)
Natural gas	1.4×10^6(4%)	0.8×10^6(1%)	0.9×10^6(1%)
Hydroelectric power	1.2×10^6(4%)	2.1×10^6(3%)	1.6×10^6(1%)
Liquefied natural gas (LNG)	–	2.4×10^6(4%)	7.7×10^6(7%)
Domestic consumption composition (m^3, oil equivalence)	29.0×10^6(100%)	58.3×10^6(100%)	100.0×10^6(100%)
Industrial sector	18.0×10^6(62%)	32.8×10^6(56%)	57.8×10^6(58%)
Transportation sector	3.8×10^6(13%)	10.0×10^6(17%)	15.3×10^6(15%)
Residential sector	3.3×10^6(13%)	6.8×10^6(12%)	11.8×10^6(12%)
Agricultural sector	1.0×10^6(3%)	1.4×10^6(2%)	1.5×10^6(1%)
Commercial sector	0.7×10^6(2%)	2.6×10^6(5%)	5.6×10^6(6%)
Non-energy sector	0.5×10^6(2%)	1.2×10^6(24%)	2.0×10^6(2%)
Others sector	1.9×10^6(7%)	3.5×10^6(6%)	6.0×10^6(6%)

[a] Ref. [5].

- The largest growth in energy supply is planned for liquefied natural gas (LNG) fired generation from 7.7 million KLOE in 2002 to 22.2 million KLOE in 2020 because LNG is one of the clean energies.
- The energy supply from indigenous production is projected from 2.5 million KLOE in 2002 to 8.5 million KLOE in 2020. The increased portion is mainly due to domestic renewable energy production from the wind energy and solar energy.
- In response to the debatable issue of the use of nuclear power in Taiwan and around the world, the government policy is planning to gradually and completely phase out the production of nuclear energy so that the portion of nuclear energy supply will not increase during the years from 2010 to 2020.
- It is forecast that a considerable portions (about 45% and 40%, respectively) of the domestic energy consumption are in the electricity generation and the direct consumption as oil, showing that the Taiwan's living level will be in line with this trend in 2020.

3. Status of greenhouse gas emissions

Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are very efficient in absorbing the infrared heat radiation emitted from Earth's warm surface while transparent to visible light. They trap

Table 5
Energy supply and demand projects during 2002–2020 in Taiwan[a]

Item	2002	2010	2020
Total supply (m^3, oil equivalence)	113.2×10^6	132.1×10^6	163.1×10^6
Indigenous	2.5×10^6(2%)	5.6×10^6 (5%)	8.9×10^6 (5%)
Imported	110.7×10^6 (98%)	126.5×10^6 (95%)	154.2×10^6 (95%)
Total supply composition (m^3, oil equivalence)	113.2×10^6 (100%)	132.1×10^6 (100%)	163.1×10^6 (100%)
Petroleum	55.7×10^6 (48%)	65.5×10^6 (49%)	76.6×10^6 (46%)
Coal	37.5×10^6 (33%)	29.8×10^6 (22%)	43.5×10^6 (27%)
Nuclear power	9.8×10^6 (9%)	13.2×10^6 (10%)	12.0×10^6 (7%)
Liquefied natural gas (LNG)	7.7×10^6 (7%)	18.1×10^6 (14%)	22.2×10^6 (14%)
Hydroelectric power	1.6×10^6 (1%)	1.1×10^6 (1%)	1.0×10^6 (1%)
Natural gas	0.9×10^6 (1%)	0.7×10^6 (1%)	0.9×10^6 (1%)
Renewable energy	0.6×10^6 (1%)	3.7×10^6 (3%)	6.9×10^6 (4%)
Domestic consumption composition (m^3, oil equivalence)	99.9×10^6 (100%)	116.8×10^6 (100%)	145.3×10^6 (100%)
Petroleum	39.3×10^6 (39%)	46.3×10^6 (40%)	59.6×10^6 (41%)
Coal	10.8×10^6 (11%)	11.6×10^6 (10%)	9.7×10^6 (7%)
Natural gas	2.6×10^6 (3%)	4.8×10^6 (4%)	6.3×10^6 (4%)
Electricity	46.6×10^6 (47%)	50.4×10^6 (43%)	62.8×10^6 (43%)
Renewable energy	0.6×10^6 (1%)	3.7×10^6 (3%)	6.9×10^6 (4%)

[a] Ref. [5].

the radiation heat in the atmosphere and then reemit it back toward the Earth. The heat balance called greenhouse effect is essential to life on Earth. Anthropogenic emissions of GHGs, however, led to a considerable increase in the concentrations of these gases in the atmosphere since the Industrial Revolution [7]. The result is expected to trigger global warming, which may cause adverse environmental disasters including coastal flooding and endanger the welfare of Taiwan since it is an island country and more than 80%of its economic activity lies in a narrow coastal plain along the Taiwan Strait. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was declared in Rio De Janeiro (Brazil), followed by the Kyoto Protocol in 1997 [8]. Subsequently, developed and developing countries around the world have prevailingly addressed the mitigation strategies and policies relating to the GHGs. It is also well known that the emissions of GHGs are closely related to the use of energy. Therefore, the upgrading of Taiwan's industries and living level has become one the major challenges to our efforts in reducing GHGs emissions.

In response to the UNFCCC and Kyoto Protocol, the Taiwan government further and actively makes its efforts to mitigate the emissions of GHGs. First of all, National Council for Sustainable Development was formally established to coordinate ministerial-level interdepartmental activities in 1997. In December 2000, the Taiwan EPA completed compilation of Taiwan's GHGs inventories, which include CO_2, CH_4 and N_2O, according to the Intergovernmental Panel on Climate Change

(IPCC) approach [9]. Under the auspices of the EPA, the Energy Commission under the Ministry of Economics Affairs, and the Council of Agriculture (COA), the emissions of CO_2, CH_4 and N_2O have been estimated using IPCC method as well as measurements. Table 6 is Taiwan's national GHGs inventories in 1990 and 2000, showing a trend towards increase in anthropogenic emissions of CO_2, CH_4 and N_2O. Table 7 lists the total CO_2 emissions from energy utilization, and its portions compared to the total CO_2 emissions and GHGs emissions in the years 1990, 1994, 1996, 1999, and 2000. Some notable points from Tables 6 and 7 are addressed as follows:

- The total GHGs emissions in Taiwan showed a rising trend between the years 1990 and 2000. The total GHGs emissions increased from 160,445 thousand metric tons of carbon dioxide equivalent in 1990 to 271,622 thousand metric tons of carbon dioxide equivalent in 2000. The growth rate for GHGs emissions averaged out at about 5.3%. It is noted that the rising trend has significantly diminished since 1998 mainly due to the GHGs emissions mitigation implantations. For example, under the policy encouragement of the Taiwan EPA and Council for Economic Planning and Development (CEPD) since 1999, there are four sanitary landfill gas (LFG) generation facilities, which are located in Nankang (Taipei city), Mucha (Taipei city), Wenshan (Taichung city) and Nantzu (Kaohsiung city) [10]. The total installation capacity of the biogas energy sums up to 22 MW. Notably, the environmental performances of the LFG energy utilization are estimated to be electricity generation 1.5×10^9 kW h/year and equivalent methane mitigation 6.5×10^5 metric ton/year.
- Taiwan started the estimation of HFCs emissions from 1992 and the emissions of PFCs and SF_6 from 1998. Compared to total GHGs emissions based on CO_2 equivalent, emission percentages of CO_2, CH_4 and N_2O in 1990 were 82.6%, 8.7% and 8.7%, respectively. In 2000, the portion of CO_2 increased up to 88.0%. The portions of CH_4 and N_2O, however, decreased down to 4.6% and 4.3%, respectively.
- Because of the rapid growth in semiconductor manufacturing industry in Taiwan in recent years, the emission of HFCs, PFCs and SF_6 has been rapidly increasing. In 1999, the emission and portion of the three GHGs based on CO_2 equivalent reached 18,135 thousand metric tons and 6.7%, respectively. The trend, however, is changing as Taiwan Semiconductor Industry Association (TSIA) formulated a voluntary reduction plan of HFCs, PFCs and SF_6 in the 2008–2012 timeframe according to the Kyoto Protocol [11]. In 2000, the emission and portion of the three GHGs based on CO_2 equivalent have been decreased to 8447 thousand metric tons and 3.1%, respectively.
- CO_2 production from the combustion of fossil energy is the main source of anthropogenic emission of GHGs from all industrialized countries in the world. Taiwan is no exception. In 1990, 75.4% of the total GHGs emissions in Taiwan were from the energy sector, and 7.2% from industrial processing sector. In 2000, these portions were changed to 84.6% from the energy sector, and 3.4% from industrial process sector. Obviously, the most of GHGs emissions came

Table 6
Main greenhouse gases emission inventory of Taiwan in 1990 and 2000[a]

Emission source/ composition	1990			2000		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Energy	120,969 (91.3%)	80.8 (12.2%)	1.4 (3.1%)	229,764 (96.2%)	111.7 (18.8%)	2.7 (7.1%)
Combustion from fuels[b]	120,969 (91.3%)	9.6 (1.5%)	1.4 (3.1%)	229,764 (96.2%)	16.8 (2.8%)	2.7 (7.1%)
Fugitive emissions from fuels	NE[c]	71.2 (10.7%)	0.0 (0.0%)	NE	94.9 (16.0%)	0.0 (0.0%)
Industrial processes[d]	11,547 (8.7%)	0.2 (0.0%)	0.6 (1.3%)	9,172 (3.8%)	0.4 (0.0%)	0.4 (1.1%)
Agriculture[e]	NA[f]	119.5 (18.0%)	41.6 (92.0%)	NA	93.6 (15.7%)	33.0 (87.1%)
Waste[g]	NE	462.8 (69.8%)	1.6 (3.5%)	NE	389.5 (65.5%)	1.8 (4.7%)
Sum	132,516 (100.0%)	663.3 (100.0%)	45.2 (100.0%)	238,936 (100.0%)	595.2 (100.0%)	37.9 (100.0%)

[a] Ref. [9]; unit: thousand metric tons.
[b] Including energy industry, manufacturing industries and construction, transport, etc.
[c] Not estimated.
[d] Including mineral products, chemical industry, metal production, etc.
[e] Including enteric fermentation, manure management, rice cultivation, agricultural soil, etc.
[f] Not applicable.
[g] Including solid waste disposal on land, wastewater handling, etc.

Table 7
Total carbon dioxide emissions from energy utilization and GHGs emissions of Taiwan in 1990–2000[a]

Year	Amount of emission from energy sector (thousand metric tons)	Total GHGs emissions (thousand metric tons of CO_2 equivalent)[b]	Percentage compared to total CO_2 emissions[c]	Percentage compared to total GHGs emissions
1990	120,969	160,445	91.3	75.4
1994	158,843	210,445	91.6	75.5
1996	175,426	226,585	92.5	77.4
1999	206,386	269,955	94.7	76.5
2000	229,764	271,622	96.2	84.6

[a] Ref. [9].
[b] Exclusive of sink sources such as land-use change and forestry. GHGs include CO_2, CH_4, N_2O, (hydrofluorocarbons) HFCs, (perfluorocarbons) PFCs and sulfur hexafluoride (SF_6).
[c] Exclusive of sink sources such as land-use change and forestry.

from the energy sector, showing that the main efforts at future GHGs reduction should be focused on energy conservation and the promotion on the use of renewable energy.

- Sanitary landfill for disposing of municipal solid waste (MSW) and anaerobic treatment of industrial wastewaters (e.g., piggery wastewater) were the main sources of methane emissions in Taiwan. Due to the incineration-combined generation that becomes the main method for treatment of MSW since 1999 and biogas thus produced from the biological process, future methane emissions should be gradually diminished. In 1994, the emission and portion of methane based on CO_2 equivalent reached 20,044 thousand metric tons and 9.5%, respectively. In 2000, its emission and portion decreased to 12,499 thousand metric tons and 4.6%, respectively.

4. Environmental impacts of renewable energy utilization

Generally, the impacts of renewable energy utilization on the environment are very minor compared to those of traditional energy utilization. However, air pollution from biomass (e.g., municipal solid waste and agricultural by-product/waste) energy utilization and other environmental considerations from hydropower and wind energy have been given increasing attention by energy industries and the public. In order to improve the living environment, the Taiwan government began to establish legislative system that prevents anthropogenic interference with the environmental system in response to major economic changes caused by rapid industrialization and structural changes at the beginning of the 1970s. In Taiwan, the basic law governing and promoting air pollution control and prevention is the Air Pollution Control Act (APCA), which was initially passed in May 1975, mainly amended in May 1982, February 1992, January 1999 and June 2002, respectively. The goal of this act is to prevent and control air pollution, safeguard public health and improve the living environment. Under the authorization of the APCA, six criteria air pollutants—particulate matter (TSP and PM_{10}), carbon monoxide, sulfur

Table 8
Ambient air quality standards in Taiwan

Pollutant	Averaging time	Frequency parameter	Concentration
Total suspended particulate (TSP)	24 hours[a]	–	250 μg/m^3
	1 year	Annual geometric mean	130 μg/m^3
Particulate matter, ≤10 μm	1 day	Daily arithmetic mean from hourly mean	125 μg/m^3
	1 year	Annual arithmetic mean from daily mean	65 μg/m^3
Sulfur dioxide	1 hour	Arithmetic mean	0.25 ppm
	1 day	Daily arithmetic mean from hourly mean	0.10 ppm
	1 year	Annual arithmetic mean from daily mean	0.03 ppm
Nitrogen dioxide	1 hour	Arithmetic mean	0.25 ppm
	1 year	Annual arithmetic mean from daily mean	0.05 ppm
Carbon monoxide	1 hour	Arithmetic mean	35 ppm
	8 hours[b]	Arithmetic mean from hourly mean	9 ppm
Ozone	1 hour	Arithmetic mean	0.12 ppm
	8 hours	Arithmetic mean from hourly mean	0.06 ppm
Lead	1 month	Monthly arithmetic mean from daily mean	1.0 μg/m^3

[a] Based on continuous sampling of 24 hours.
[b] Based on continuous sampling of 8 hours.

dioxide, nitrogen dioxide, ozone and lead—were chosen to be included in the Ambient Air Quality Standards, which was first issued by the EPA in April 1992 and listed in Table 8. Table 9 lists the monitoring data of these criteria air

Table 9
Monitoring data of criteria air pollutants in Taiwan[a]

Year	PM_{10}[b] (μg/m^3)	SO_2 (ppm)	NO_2 (ppm)	CO (ppm)	O_3 (ppm)
1995	67.48	0.009	0.024	0.92	0.022
1996	64.47	0.007	0.024	0.96	0.023
1997	62.72	0.006	0.024	1.03	0.022
1998	58.15	0.006	0.023	0.80	0.022
1999	59.95	0.005	0.023	0.74	0.023
2000	59.37	0.004	0.022	0.70	0.024
2001	57.87	0.004	0.021	0.73	0.025
2002	54.28	0.004	0.019	0.60	0.027
Air quality standard[c]	65	0.03	0.05	–	–

[a] Ref. [1]; data calculation is based on annual average.
[b] Denoted as particulate material, particle size ≦ 10 μm.
[c] Referred in Table 8.

pollutants in the years 1995–2002, showing that the air quality in Taiwan is currently in the good level. The annual averages tend towards decrease, excluding ozone. Regarding the air pollution control, there are three important provisions or regulations concerning emission standards for biomass waste-to-energy facilities, which are briefly described as follows:

4.1. Waste incinerator air pollutants emission standards

MSW incineration with heat recovery (i.e., cogeneration) is one of the important energy utilizations in Taiwan. However, it is well known that the thermal process has the potential of emitting diversified air pollutants to the environment. These potential emissions may arise from compounds (e.g., heavy metals) present in the waste stream, are formed as a part (e.g., particulate and acid gases) of the normal combustion process, or are formed as a result (e.g., carbon monoxide) of incomplete combustion. Table 10 lists the air pollution control standards for waste incinerator emissions, which was first issued by Taiwan EPA in November 1992. In Taiwan, the wastes are classified into general waste and industrial waste according to the definition of the Waste Disposal Act (WDA). It is noted that MSW incinerators in Taiwan are facing the decline of general waste generation because of promotion on resource recovery, green consumption and green procurement since 1997. To maintain the stable operation of cogeneration in the MSW incineration facilities, these incinerators are being permitted to incinerate general industrial

Table 10
Emission standards of air pollutants from incinerator of municipal solid waste (MSW) in Taiwan

Standards[a]	Treatment quantity			
	<2 MT/h[b]	2–10 MT/h	≥10 MT/h (existing)	≥10 MT/h (new)
Opacity (%)	20	20	20	20
Particulate matter (mg/Nm^3)	220	Conversion by effluent rate:	$C = 1364.2Q^{-0.368}$ ($C \leq 220$)	Q: effluent rate (Nm^3/min)
Sulfur oxides (as sulfur dioxide) (ppm)	300	220	150	80
Nitrogen oxides (as Nitrogen dioxide) (ppm)	250	220	220	180
Hydrogen chloride (ppm)	60	60	60	40
Carbon monoxide (ppm)	350	350	150	120
Lead and its compounds[c] (mg/Nm^3)	7	3	3	3
Cadmium and its compounds[c] (mg/Nm^3)	–	0.7	0.5	0.3
Mercury and its compounds[c] (mg/Nm^3)	–	0.7	0.5	0.3

[a] Concentration calculation of air pollutant in the stack gas must be based on 273 K, 1 atm and dry volume of undiluted effluent. Also, 10% O_2 (oxygen content) is referred as correction baseline.

[b] Denoted as metric ton per hour.

[c] Including solid-phase sample.

wastes from workshops such as wood wastes and agricultural wastes by local government authorities of Taiwan.

4.2. Waste incinerator dioxin control and emission standards

While there is concern about the emissions of acid gases and heavy metals from waste incinerators, probably the most controversial pollutants from incinerator emissions are the categories of chlorinated organics (i.e., dioxins/furans, or referred to PCDDs/PCDFs), which may be formed as a result of incomplete combustion and have been found in the stack gas of MSW and industrial waste incinerators [12]. These compounds are of concern mainly due to their high toxicity in the laboratory animals, and endocrine-disrupting in the wildlife and humans [13]. With the policy for MSW incinerator construction project of 1990s in Taiwan, it is estimated that there are over 30 large-scale MSW incineration facilities to be operated in the end of 2006. By that time Taiwan may be ranked No. 1 in large-scale incinerator density in the world. It implies that dioxin emissions from these incinerators may adversely affect human health. Therefore, the emission standards for new and existing waste incinerators that were seriously developed and first promulgated by Taiwan EPA in August 1997 under the authorization of APCA, as shown in Table 11. Basically, the emission standards stipulate that dioxin level of incinerator stack must comply with the standard limit of 0.1 ng-TEQ/Nm^3, which may be the most stringent regulation on dioxin control in the world [14].

4.3. Emission standards of air pollutants from stationary sources

Taiwan lies in the subtropical and tropical zones and has about 2000–2500 mm per year in rainfall. The climate is very favorable for the cultivation of energy crops such as sugarcane and forest. Due to the high-energy content (about 4000 kcal/kg, dry basis) in the cellulosic by-products or wastes, some sugar mills and paper and pulp factories successfully adopted direct combustion for the purpose of energy utilization in Taiwan. However, it is noted that the thermal process has the potential of emitting diverse types of air pollutants to the environment. These

Table 11
Emission standards of dioxin from incinerator of municipal solid waste (MSW) in Taiwan

Treatment quantity	Standard (ng-TEQ/Nm^3)[a]	New/existing facility	Effective date
<4 metric ton/h	0.5	New	8/8, 1997
		Existing	8/8, 2001
4–10 metric ton/h	0.1	New	1/1, 2001
		Existing	1/1, 2003
≥10 metric ton/h or ≥300 metric ton/day	0.1	New	1/1, 2001
		Existing	1/1, 2004

[a] Calculated based on toxic equivalent factors (TEFs) of polychlorinated dibenzo(p)dioxins/polychlorinated dibenzofurans (PCDDs/PCDFs).

Table 12
Stack emission standards of air pollutants from stationary sources in Taiwan

Item	Standards[a]	Comment
Opacity (%)	20%	Not available for small-scale (<2500 c.c.) internal engine
Particulate matter (mg/Nm^3)	Conversion by effluent rate: $C = 1860.3\ Q^{-0.386}$ $(25 \leq C \leq 500)$; Q: effluent rate (Nm^3/min)	
Sulfur oxides (as sulfur dioxide) (ppm)	100 (combustion process, gas fuel) 300 (combustion process, liquid fuel) 300 (combustion process, solid fuel) 650 (sources excluding combustion process)	
Sulfuric acid droplet (mg/Nm^3)	100 (sulfuric acid plant) 200 (sources excluding sulfuric acid plant)	
Nitrogen oxides (as Nitrogen dioxide) (ppm)	150 (combustion process, gas fuel) 250 (combustion process, liquid fuel) 350 (combustion process, solid fuel) 250 (sources excluding combustion process)	Only available for new emission sources (Facility was installed after April 10, 1992)
	350 (combustion process, gas fuel) 400 (combustion process, liquid fuel) 500 (combustion process, solid fuel) 500 (sources excluding combustion process)	Only available for existing emission sources (Facility was installed prior to April 10, 1992)
Hydrogen chloride	80 ppm or $\leq$1.8 kg/h	
Chlorine (ppm)	30	
Carbon monoxide (ppm)	200	
Total fluorides (as F^-) (mg/Nm^3)	10	
Hydrogen sulfide (ppm)	100 (directly vented to atmosphere) 650 (inlet concentration prior to combustion treatment)	
Lead and its compounds (mg/Nm^3)	10	
Cadmium and its compounds (mg/Nm^3)	1	
Asbestos and its compounds (mg/Nm^3)	Invisible by naked eye	
Vinyl chloride (ppm)	10	

[a] Concentration calculation of air pollutant in the stack gas must be based on 273 K, 1 atm and dry volume of undiluted effluent. Also, 6% O_2 (oxygen content) is referred as correction baseline.

potential emissions may arise from compounds (e.g., heavy metals) present in the waste stream, are formed as a part (e.g., particulate and acid gases) of the normal combustion process, or are formed as a result (e.g., carbon monoxide) of incomplete combustion. Table 12 lists stack emission standards of air pollutants from stationary sources in Taiwan, which was first issued by the EPA in April 1992.

On the other hand, the preventative approach towards environmental protection and pollution prevention started in the end of 1980s in Taiwan. Obviously, the

introduction of environmental impact assessment (EIA) could significantly strengthen the prevention and mitigation of adverse impacts at the early stage of development activities. Article 5 of the Environmental Impact Assessment Act (EIAA), first promulgated in December 1994 and recently revised in June 2002, authorizes the EPA to conduct EIA for the development activities that are likely to cause adverse impacts on the environment. Further, a regulation (i.e., "Working Guidelines for Environmental Impact Assessment of Development Activities") promulgated by the EPA under the authorization of the EIAA requires those prescribed development activities that EIA shall be conducted, including the construction of municipal solid waste/general industrial waste treatment facilities (i.e., sanitary landfill and incineration plant) and the exploitation of wind energy. For example, EIA shall be conducted for the wind power generation facilities, which are located in one of the following sites, or comply with the generation capacity or accumulative generation capacity requests:

- Location in national parks.
- Location in wildlife protection areas or important wildlife habitats.
- Location in land for city use, and over 25,000 kW.
- Location in land for non-city use, and over 50,000 kW.

5. Promotion policies for encouraging renewable energy

Renewable energy is a sustainable and clean energy derived from natural sources. The National Energy Conference was convened in May 1998 so that the new and clean energy was thus actively promoted. Target share from renewable energy in term of installation capacity is 10% of the total by 2020, as listed in Table 13 [6]. Table 14 shows the development target at renewable energy, including hydropower, wind energy, solar energy, biomass energy and geothermal energy [6]. In order to encourage the use of the clean energy in Taiwan, the current promotion regulations related to renewable energy utilization are mainly based on the Statute for Upgrading Industries (SUI), which was originally promulgated and became effective in December 1990 and was thereafter revised in January 1995, January 2002 and February 2003, respectively. According to the newly revised

Table 13
Estimation of installation cost and output energy for renewable energy development in Taiwan[a]

Item	Short term (2000–2004)	Moderate term (2005–2009)	Long term (2010–2020)
Cumulated installation cost (US$ million)	644	2585	10,135
Cumulated annual production (KLOE, $\times 10^4$)	284	434	748
Cumulated capacity (kW, $\times 10^4$)	236	363	650
Cumulative electricity generation (kW h, $\times 10^8$)	96	146	250

[a] Ref. [6].

Table 14
Development goal of renewable energy in Taiwan[a]

Item	2001		2010		2020	
	Performance	%	Goal	%	Goal	%
Hydroelectric energy	1819 MW	81.7	2050 MW	62.1	2500 MW	38.5
Wind energy	5 MW	0.2	500 MW	15.2	1500 MW	23.1
Geothermal energy	–	0	–	0	150 MW	2.3
Solar photovoltaics	0.3 MW	0	55 MW	1.7	1000 MW	15.3
Solar thermal energy	(103×10^4 m^2)	–	(350×10^4 m^2)	–	(600×10^4 m^2)	–
Biomass energy	403 MW	18.1	695 MW	21.0	1350 MW	20.7
Sum	2227 MW	100	3300 MW	100	6500 MW	100

[a] Ref. [6].

SUI, important features concerning the aspects of waste-to-energy include as follows:

1. To provide the financial incentives for any of the listed purposes (e.g., employing new and clean energy), after-sales service to instruments and equipment purchased by a company may be extended to two years; however, if there is any post-depreciation residual value during the extended after-sales service, assets depreciation may continue in one year or several years within the after-sales service to such assets as specified in the Income Tax Law until depreciation is fully made (Article 5).
2. To meet the requirement for industrial upgrading, an enterprise may credit 5–20% of the amount of fund disbursed for any of the listed purposes (e.g., The fund invested in the equipment or technology used for employing new and clean energy) against the amount of profit-seeking enterprise income tax payable for the current year (Article 6).
3. In order to encourage the incorporation or expansion of the newly emerging, important and strategic industries (thereafter announced by Ministry of Economics Affairs in December 2001, including biogas generation equipment, and emerging/clean energy utilization service) that can produce substantial benefits to economic development, an investor (profit-seeking enterprise or individual), who subscribes to the registered stock issued by the company and has held such stock for a period of three years or longer, may deduct the profit-seeking enterprise income tax or the consolidated income tax up to 20% and 10% of the price paid for acquisition of such stock for profit-seeking enterprise and individual, respectively (Article 8).
4. The Executive Yuan shall establish a development fund for low interest loans and make use of such development fund for the listed purposes (e.g., reduction of greenhouse gas effects) (Article 21).
5. In order to advance technologies, enhance R&D activities and further upgrade industries, the relevant central government agencies in charge of end enterprises may promote the implementation of industrial and technological projects by providing subsidies to such R&D projects (Article 22-1).

Under the authorization of Article 6 of SUI, the regulation, known as "*Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy conservation, or emerging/Clean Energy Organizations*", has first been promulgated by the Ministry of Finance (MOF) in July 1997, and thereafter revised in November 1999, July 2000, September 2001 and January 2003, respectively. These specified organizations shall be granted credits on the profit-seeking enterprise income tax for the current year if they themselves use these equipments and/or technologies according to the following percentages of total purchase cost (>NT$ 600,000) in the current year:

- 13% for emerging/clean energy utilization equipments.
- 10% for emerging/clean energy utilization technologies.

If the profit-seeking enterprise income tax for the current year is not enough to be granted a tax deduction for investment, they may deduct the tax in the next 4-years for their profit-seeking enterprise income taxes. According to Provision 2 of the regulation, the equipments for emerging and clean energy utilization are specified to include the following items:

- Electricity generation equipments from wind energy.
- Equipments, including electricity generation, thermal utilization, air conditioning etc., for geothermal energy utilization.
- Related equipments, including electricity generation, thermal utilization and various derived-fuels, for waste energy recovery and utilization.
- Equipments for solar photovoltaic system.
- Equipments, including thermal collector and cooling/air conditioning system, for solar energy utilization.
- Electricity generation facilities from fuel cell.
- Equipments, including electricity generation from biomass materials, and production for alcoholic gasoline and bio-diesel, for biomass energy utilization.
- Equipments for ocean energy utilization.
- Equipments for small-scale hydroelectric power.

Also, the emerging/clean energy utilization technologies pointed out in the regulation referred to patents, technologies for a specified purpose, and computer package softwares that are necessary for the use of the equipments described above. On the other hand, under the funds of the Energy Commission under the Ministry of Economics Affairs (MOEA) and the National Science Council (NSC), many researchers' science and technology projects place emphasis on fuel cell, renewable energy (especially solar energy) and hydrogen energy at research and development (R & D) laboratories in recent years. For example, Energy and Resources Lab of Industrial Technology Research Institute (ITRI) acts as consulting group to assist industries in adopting and implementing energy utilization from gasification of agro-waste (i.e., rice husk) and wind power [15]. Chia Nan University of Pharmacy and Science (Tainan, Taiwan) has conducted research on fast pyrolysis for local

mass agro-wastes such as rice husk, rice straw, bagasse and coconut shell under the funding of the Energy Commission of MOEA in the "Energy Technology Project". It has demonstrated that the advanced process can enhance the yield of bio-crude for the purpose of in situ production and ease storage [16].

Besides the promotion incentives from SUI, under the authorization of the Article 39 of the newly revised Waste Disposal Act (WDA), the responsible agencies at the central government level have promulgated the regulations (i.e., "Regulations Governing the Permitting of Industrial Waste Reuse") related to industrial waste reuse by the Ministry of Economic Affairs (MOEA) in January 2002. According to the definition of the regulation, industrial waste can be directly reused without compliance with the requirements of intermediate treatment and final disposal. The term "reuse" should refer to the industrial waste reused by the waste producers themselves, or sold, or transferred or entrusted to others for reuse as raw material, material, fuel, engineering filler, soil modification, reclaimed land, land-fill or for other approved purposes. Of these announced wastes, scrap woods (whole/part) and bagasse can be legally permitted to be reused as fuel [4].

In order to facilitate renewable energy utilization and supply from natural resources such as wind and solar energy, and save traditional energy usage, there are three promotional regulations issued by the Energy Commission of the Ministry of Economic Affairs in the assistance supports.

5.1. Assistance regulations governing demonstration system installation for electricity generation from wind energy

The regulation was first issued on March 22, 2000, and recently revised on February 12, 2003. The system owner who has received the assistance must be in harmony with the Energy Commission of the Ministry of Economic Affairs to conduct demonstration activities, and regularly supply operation and maintenance data in public. The important features are summarized as follows:

- The assistance rating standard is set up below NT$ 16,000/kW (≒US$ 450/kW). Also, the maximum assistance amount does not exceed a half of total installation cost of the electricity generation demonstration system from wind energy. The rating applied to assistance and then examined by the rating council multiplied by the installation capacity equals the assistance amount.
- The regulation is effective prior to December 31, 2004.

5.2. Assistance regulations governing solar water heater system

The regulation was recently issued on February 6, 2003. The performances and specifications of solar water heaters that can be applied to assistance must comply with the qualification standards by the establishment of the Energy Commission under the Ministry of Economic Affairs (MOEA). Also, these solar collectors should be manufactured from the quantified manufacturers (i.e., certified by ISO

9000 series, or equivalent certifications). The important features are summarized as follows:

- The assistance rating standard is set up at NT$1,000–3,000/m^2, which is mainly dependent on the types of solar waterheater.
- The regulation is effective prior to December 31, 2004.

5.3. Assistance regulations governing demonstration system installation for electricity generation from solar photovoltaics

The regulation was issued on March 6, 2002. The installation capacity of system that is applied for assistance should be at least 1 peak kilowatt (PK), which is defined as the maximum electricity generation capacity of the solar photovoltaic system under solar radiation. The important features are summarized as follows:

- The assistance rating standard is set up below NT$ 150,000/PK. Also, the maximum assistance amount does not exceed one half of total installation fee of the solar photovoltaic demonstration system. The rating applied for assistance and then examined by the rating council multiplied by the installation capacity equals the assistance amount.
- The implementation schedule is effective from March 8, 2002 to December 31, 2004.

In order to further integrate and coordinate the tasks of promoting the continual use of renewable energy, the Executive Yuan adopted the "Renewable Energy Development Plan" in January 2002. The Council for Economic Planning and Development will be in charge of coordinating the efforts from central government authorities in promoting renewable energy. In the Plan, important measures and promotions, which are partly described above and shall be conducted in recent years, are summarized as follows:

- Enact legislation for the Statute for Renewable Energy Development.
- Request the Taiwan Power Company (government-owned enterprise) to set up "Procurement Regulation Governing Electricity from Renewable Energy" and "Guidelines Governing the Parallel Electricity Generation Technologies from Renewable Energy".
- Consecutively promote sanitary landfill biogas for electricity generation under funding of the air pollution control fee of APCA by EPA prior to the legislation of the Statute for Renewable Energy Development.
- Give the financial incentives, including investment subsides (income tax subsides) and low-interest loans, to enterprises/businesses that utilize renewable energy equipments and technologies. These financial incentives are under consideration to expand into parties, organizations, etc.
- Enhance the demonstration and publicity for renewable energy utilization, and set up the assistance regulations for encouraging installation by enterprises/businesses.

- Establish the databank of renewable energy, and continuously research and develop high-efficiency, low-cost, commercialization-scale production technologies and stable electricity-supply technologies on renewable energy.
- Set up the feasible approaches to the acquisition of land and alteration of land use for electricity generation system (above the specified scale) and its parallel loop from renewable energy. Their applications and examinations shall be designated to the operation procedure and deadline, or achieved through the revision of related regulations.
- Guide the industrial development on renewable energy sector, and assist the sector in promoting for the development of low-cost, commercial production technologies and products.
- Add and encourage the installation of solar photovoltaic system as one of the examination items during the examining process of public facility construction under no large amplitude increase in total budget.

Among these promotion measures, it is the most notable that the procurement charge of electricity from renewable energy will be guaranteed at fixed rate of NT$ 2.0/kW h (≒US$ 0.06/kW h) by the Statute for Renewable Energy Development (Draft) [17], compared to other developed countries in Table 15. Also, subsidy will be provided to reduce the capital costs on some renewable energy utilization equipments. The law aims at the total promotion amount of 3300 and 6500 MW in 2010 and 2020, respectively. Also, the Taiwan government is actively proceeding with R & D and promotional applications on renewable energy, and planning to demonstrate Solar City, Wind Farm and Geothermal Park in the Challenge 2008—National Development Plan [18].

Table 15
List of purchasing rate for renewable energy

Country	Purchasing rate[a,b] (NT$/kW h)	Average electricity rate (NT$/kW h)	Ratio (%)
USA	1.05	2.33	45
Germany	1.81 (wind energy)	3.05	59
	14.85 (solar photovoltaics)		488
Japan	2.4 (wind energy)	5.29	45
	6.67 (solar photovoltaics)		126
Spain	2.66	4.05	66
Demark	4.2	6.16	68
Taiwan[c]	2.0	2.12	94

[a] Ref. [17].
[b] Exchange rate: 1 US$ – 34 NT$ (New Taiwan dollar), 1 Yen – 0.266 NT$, 1 Mark – 15 NT$.
[c] Equipment subsidy for solar photovoltaics.

6. An overview of current renewable energy usage

Due to its geographical features, Taiwan has substantial reserves of renewable energy sources, especially in biomass, solar, wind and geothermal energy. In 2002, renewable energy production represented about 0.6 million KLOE as listed in Table 5. More than 80% of this production was supplied by biomass sources, including municipal solid waste, animal waste and agricultural by-products. Based on the substantial reduction of GHGs and other air pollutants emissions from the utilization of renewable sources compared to the use of fossil fuels and biomass wastes, the current government policies described above for the promotion of renewable energy will tend towards decrease in the use of biomass wastes and other combustible wastes, and we will expect a progressive increase in the solar energy and wind energy in the near future. According to the "Renewable Energy Development Plan" in Taiwan, the government projections during the years from 2002 to 2020 indicate that the electricity generation capacity from renewable energy will increase up to about 10% of total installation capacity of electricity generation. By the end of 2020, the accumulative installation capacity will be expected to have about 6.5×10^6 kW. The total energy and environmental performances from the Plan were estimated to be about 7.5 million KLOE and about 2.2×10^7 metric tons in the equivalent emission reduction of carbon dioxide. With respect to the economic benefits, it is equivalent saving about US$ 800 millions on imported energy and making an investment of about US$ 900 millions in domestic renewable energy equipments. The following is an overview of current renewable energy used in Taiwan.

6.1. Biomass energy

Since the energy crisis in the 1970s, the energy utilization from biomass resources has received much attention in Taiwan. The energy in biomass (called biomass energy) from plants, animals (that eat plants or other animals) or wastes that they are thus produced originally comes from solar energy through the photosynthesis process. The energy supply from domestic waste materials is especially noticeable in that it not only eliminates the environmental pollution but also saves on fuel cost in the manufacturing/processing industries. Of the many energy productions from combustible or biological materials, municipal solid waste and agricultural wastes/by-products, in particular, seem to be attractive based on bioresource sustainability, environmental quality and economic consideration. The energy obtained from these bioresources is a form of renewable energy. Basically, utilizing this energy does not add carbon dioxide to the atmospheric environment in contrast to fossil fuels [19]. Due to the lower contents of sulfur and nitrogen in biomass resources, its direct utilization as fuel and/or electricity generation in the combustion process generally pollute the environment and risk our health less than either nuclear power or fossil fuel power. Also, biomass energy stores more easily than energy system using solar energy, which requires separate and expensive storage facility [20].

According to the data examined by the EPA [1], 56.8% (approximately 3819 thousand metric tons), 30.8% (approximately 2071 thousand metric tons), and 11.6% (approximately 776 thousand metric tons) of MSW were currently treated by incineration, sanitary landfill and recycling, respectively. Under the current waste treatment policy, the Taiwan EPA has adopted a strategy favoring incineration as the primary treatment method and sanitary landfill as a supplement. Twenty-one large-scale incinerators will be constructed by the end of 2005, at which the MSW incineration rates can be expected to reach 80% and above. It is noted that these mass burn incinerators will generate lots of marketable electricity through steam turbine-generator (cogeneration) system based on total design power generation (i.e., about 450,980 kW). On the other hand, biogas production from sanitary landfill represents one of potential green energy or renewable energy from the viewpoint of sustainable development because its composition mainly includes methane and carbon dioxide. Until the mid-1990s, in order to mitigate greenhouse gas emissions from LFG based on United Nations Framework Convention on Climate Change (UNFCCC), the Taiwan government was active in coordinating private sector to construct LFG-generation facility since 1999 under the policy encouragements of the EPA and Council for Economic Planning and Development (CEPD). Currently, there are four LFG generation facilities, which are located in Nankang (Taipei city), Mucha (Taipei city), Wenshan (Taichung city) and Nantzu (Kaohsiung city) [10]. The total installation capacity of biogas energy sums up to 22 MW. Notably, the economic and environmental performances of the LFG energy utilization are estimated to be 1. 5×10^9 kW h/year and 1.55×10^7 metric tons of equivalent carbon dioxide reduction, respectively.

Since rice hull, rice straw, bagasse and con cob are the most abundant cellulosic agrowastes in Taiwan [21], these bioresources have been used directly (e.g., burning them for heating and electricity generation) using the thermo-chemical methods [22,23], or indirectly by bio-converting them into available liquid fuels (e.g., alcohol from sugar crops) [24]. On the other hand, the hogs raised in Taiwan have always maintained a number of over 7 million heads in the past decade. The hog farms come with lots of amount of pollution resulting from the animal wastes or animal-based agrowastes (i.e., feces and urine). It has also been suggested that the three-step treatment system (i.e., solid–liquid separation, anaerobic fermentation and activated sludge process) be considered most suitable for Taiwan conditions [25]. Further, the biogas generated from anaerobic fermentation has been used as an energy source for heating, cooking or electricity generation. It should be also noted that biomass wastes such as wood wastes from paper and pulp mills and wood constructions were practically combusted in furnaces and boilers to produce process heat or steam. Recently, another approach is to co-combust with solid fuel in coal fired power plant, or municipal solid waste (MSW) incineration plants for the purpose of the higher energy efficiency than household cooking and space heating.

6.2. Solar energy

Taiwan lies in a sunny zone between 21° N and 25° N latitudes, which is sufficient to provide the most promising renewable energy resource for solar water heating and photovoltaic applications. Under the government encouragements since mid-1980s, the accumulated installation area of heat collectors in Taiwan has reached 1 million m^2 for solar water heaters between the years 1985–2001. The accumulated area is projected to be 1.3 million m^2 by 2004 [6]. For photovoltaic (PV) demonstration systems, the total capacity that has been approved for subsidization was about 530 kW between the years 1990–2001. The short-term promotion target is to install demonstration systems with a total capacity of 6.7 MW by 2004, i.e., 300 kW in 2000, 400 kW in 2001, 1000 kW in 2002, 2000 kW in 2003 and 3000 kW in 2004 [26].

Under the funds of the Energy Commission since 2000, Material Research Laboratories (MRL) of Industrial Technology Research Institute (ITRI) plays a window on accepting subsidy application for installing PV power demonstration systems, providing technological inquiries and promotion activities with relation to the economic and environmental benefits of PV power [26]. The goal of PV demonstration systems in 2000 was 300 kW. There were 17 applications, including three applicants from government, six applicants from school, five applicants from industry and three individual applicants. The capacity was totally 289 kW. However, only eight applications signed the demonstration contracts due to the limitation of relevant regulations. In 2001, 33 applications were filed and granted their subsidies by the Energy Commission, including eight applicants from government (e.g., the Office of the Taiwan President), 12 applicants from school, six applicants from industry and seven individual applicants. Total approved capacity increased to 253 kW. Another target of this 5-year project sponsored by the Energy Commission is to develop thin film solar cell technologies to reduce the fabrication cost without scarifying energy efficiency.

Taiwan is very abundant in solar energy. The sun shines more than 3000 hours annually, especially in central and southern Taiwan. Flat-plate solar collectors have been widely used for over 90% domestic (household) hot-water production. About 0.89 million m^2 of collectors were installed during the years from 1986 to 1999, including 475,850 m^2 in southern Taiwan (53%), 307,390 m^2 in central Taiwan (35%), 94,600 m^2 in northern Taiwan and 10,660 m^2 in eastern Taiwan (1%). It was also predicted that the total energy and environmental performances are about 0.074 million KLOE and about 2.1×10^5 metric tons in the equivalent emission reduction of carbon dioxide [27]. According to the government promotion on solar collector installation since 2000, Table 16 lists the short-term and long-term promotion targets of solar water heaters during the years from 2000 to 2020 [28], showing that the 707 million m^2 of accumulated installation area, 12.2% of saturation rate, 0.41 million KLOE per year and 115.6×10^4 metric tons of equivalent carbon dioxide reduction per year are projected by the Energy Commission.

Table 16
Promotion target of solar water heaters Taiwan[a]

Target	2000	2005	2010	2015	2020	Total
Annual installation area (1000 m^2)	120	220	320	370	420	–
Cumulated installation area (1000 m^2)	1020	1920	3320	4460	7070	18,000
Energy benefit (million KLOE per year)	0.080	0.136	0.221	0.322	0.410	1.055
Equivalent CO_2 reduction (million metric ton per year)	0.225	0.382	0.624	0.908	1.156	3.258

[a] Ref. [28].

6.3. *Wind energy*

In recent years, wind power is the great success in the renewable energy development around the world, especially in Germany, Denmark and the Netherlands [29]. There are a number of regions in Taiwan with relatively high wind speeds, which are over 5–6 m/s at a height of 10 m as basis of annual arithmetic mean. Obviously, these conditions have exceeded ideal wind speed (i.e., 5 m/s) for producing electricity economically [8]. These regions are mainly located in western and southern coasts of Taiwan and Penhoo county about 40 miles west of Taiwan. It was estimated that the potential power production is about 1000 MW [30]. Under the funds of the Energy Commission on wind power demonstration systems since 2000, the short-term target during the years from 2000 to 2004 is 18 MW. The total capacity that has been approved for subsidization was 8.54 MW by the end of 2002, including 2.64 MW Mai-Liao system (Yunlin county) in 2000, 2.4 MW Chung-Tun system (Penghu county) in 2001 and 3.5 MW Chu-Pei (Hsinchu county) in 2002 [30].

Taiwan's first wind power demonstration system was commissioned in 2000. Under the policy supports, assistance incentives and economic considerations, it was summarized that the total installation capacity will be about 630 MW to be under planning for the near future, in that the corresponding investment amount is about US$ 800 millions [30]. However, the government policy, economic assistance and site land acquisition play determining factors prior to the commercial establishment of wind power demonstration systems. Unfortunately, it is also noted that modern wind generators have some drawbacks. First, they are regarded as being aesthetically objectionable and noise sources. Second, they may be killers for animals such as bird. Third, a successful case of wind power generation depends on the steady and abundant source of wind, not on seasons. Therefore, wind power will probably be increasingly used in Taiwan, but it is unlikely to produce the renewable energy in the long-term energy supply.

6.4. Geothermal energy

Geothermal power is a potential energy source to volcanic regions and areas with hot springs and geysers, so that it can provide heat for running steam generators or for the purpose of heating. Taiwan is one of the countries in the world famous for hot spring, which has high geothermal potential. The potential of geothermal power is estimated at about 500 MW [31]. The first geothermal researches and exploitations in Taiwan started in the mid-1970s, especially in the Ching-Shui (Yilan county) project. Unfortunately, the development project was not successful and thereafter continued to proceed with it. In 1998, this project was restarted to develop a geothermal power demonstration park based on the government policy and advanced technologies on geothermal energy. The Energy Commission was working with local government to construct demonstration generation system with multi-purpose utilization. The target is to assist in promoting at least 5 MW of geothermal power generation [6].

7. Conclusion and perspectives

Since the Rio Declaration from the Earth Summit in 1992, the energy supply and consumption relating to global warming has been focused on pursuing sustainable development and raising clean energy in recent years around the world. In response to the global environmental issues, the Taiwan government formally established the National Council for Sustainable Development in 1997. In 1998, a National Energy Conference mainly concluded with targets of formulating renewable energy development strategies and promotion measures. This paper presents an overview profile on renewable energy sources in Taiwan and their potential contributions to domestic energy supply and greenhouse gas emissions reduction. The available renewable energy options that are considered in the paper include biomass energy, solar energy, wind energy and geothermal energy. In this context, energy supply and consumption situation and emission inventories of greenhouse gases have been analyzed and addressed using the government statistical data (i.e., yearbook and annual report). In the past five years (1998–2002), the environment, economic and energy (3E) policies in Taiwan have switched from regulation establishment, information and technology transfer, and training and education in the early development stage, to provide assistance incentives and financial support to industries in adoption of renewable energy. It is undoubtedly expected that the Statute for Renewable Energy Development under enactment will further drive the gradual displacement of traditional fuels and fossil energy because of crude oil/natural gas shortage, nuclear waste safety and the high costs of maintaining the clean environment. However, many measures that promote the implementation of renewable energy utilization should be considered as follows:

- Require high energy consumption industries (e.g., steel, paper and pulp, petrochemical and cement manufacturing) to make net energy reduction by the adoption of renewable energy.

- Combine "green" costs (e.g., carbon or energy tax) with accounting system of enterprise or business.
- Involve renewable energy utilization into the certification of ISO-14000 series; that is, the waste-to-energy is considered as one of environmental performances.
- Develop "green" building code/label with installing solar energy utilization equipments such as photovoltaic power system.
- Encourage the state-owned enterprises to cultivate energy crops such as sugarcane and sunflower.
- Overcome the hindrance to site land acquisition, especially in wind energy.
- Raise the electricity rate or imported energy tax in order to further subsidize renewable energy development based on the inferior commercial competition at an early stage.
- Increase the share of the Air Pollution Control Fee (mainly original from an excise tax on gasoline), which is now managed by the EPA, for the purposes of renewable energy development based on the carbon dioxide production.

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